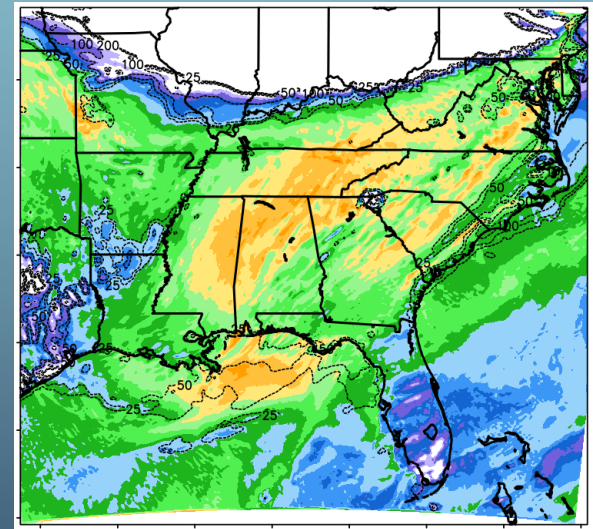
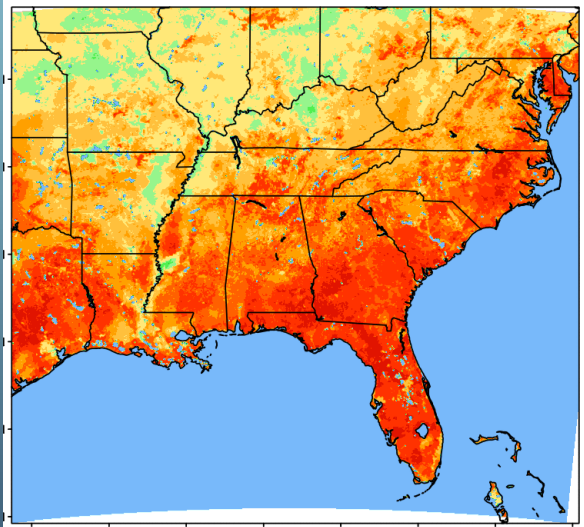


# Land Surface Model Assimilation of SMOS Soil Moisture Retrievals



Clay Blankenship (USRA)  
Jonathan Case (ENSCO Inc.)  
Bradley Zavodsky (NASA)

NASA-Marshall Space Flight Center (Huntsville, Alabama USA)  
Short-Term Prediction Research and Transition (SPoRT) Center

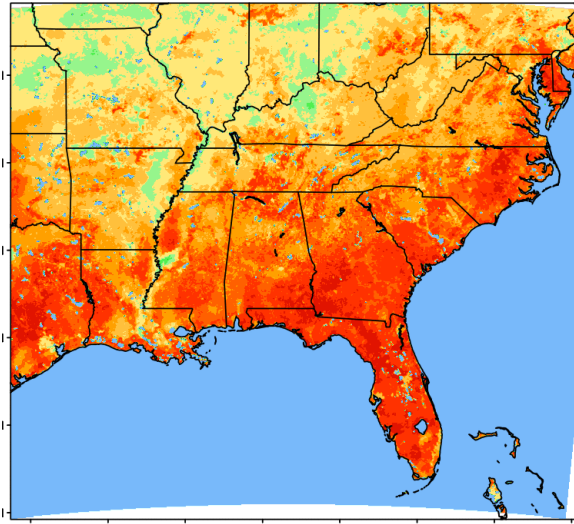


# Objectives

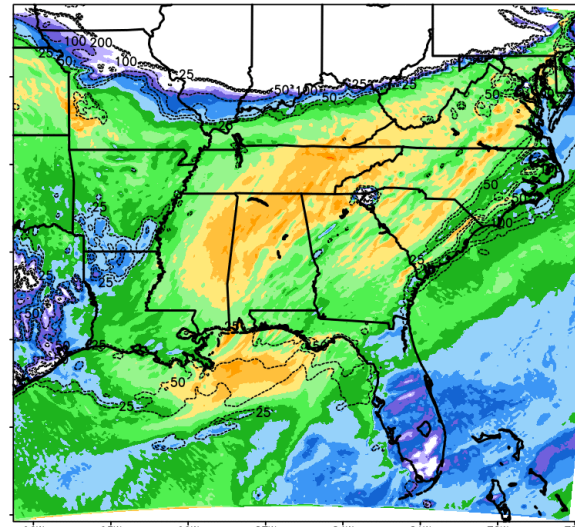
Goal: Assimilate SMAP satellite retrievals of soil moisture into a regional land surface model.

- Demonstrate impact on: LSM soil moisture field  
coupled NWP forecasts
- Transition a real-time version of LIS output to end users.

Using SMOS assimilation to prepare for SMAP.



*LIS Noah near-surface soil moisture*



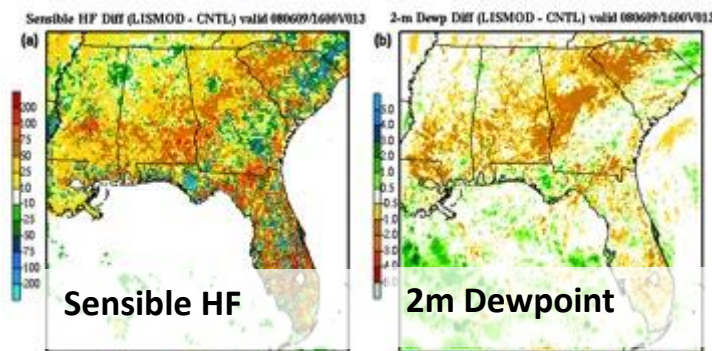
*WRF Convective Available  
Potential Energy (CAPE)*

# Motivation

- Improve model depiction of soil moisture and related variables  
(Direct Applications)  
drought monitoring, flood forecasting, agriculture



- Better numerical weather forecasts using coupled NWP/LSM  
Available moisture affects humidity, sensible/latent heating, diurnal heating rate, and convection.





# Short-term Prediction Research and Transition (SPoRT) Center

**Mission:** Transition unique NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale.

- Close collaboration with numerous WFOs and National Centers across the country
- SPoRT activities began in 2002, first products to AWIPS in 2003
- Co-funded by NOAA since 2009 through Proving Ground activities
- Proven paradigm for transition of research and experimental data to operations

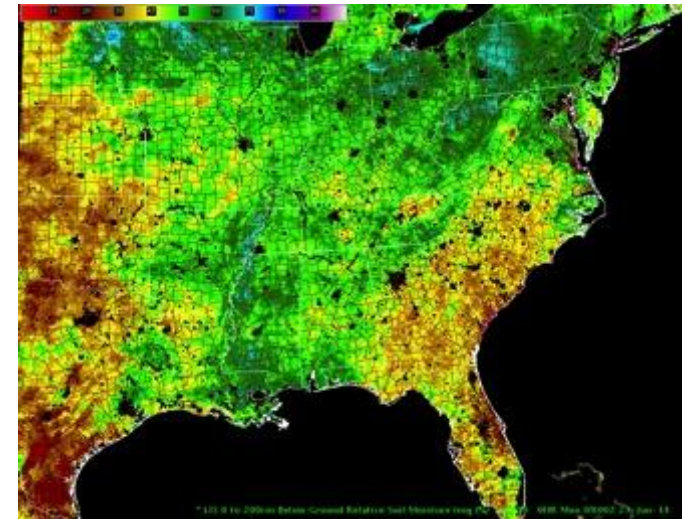
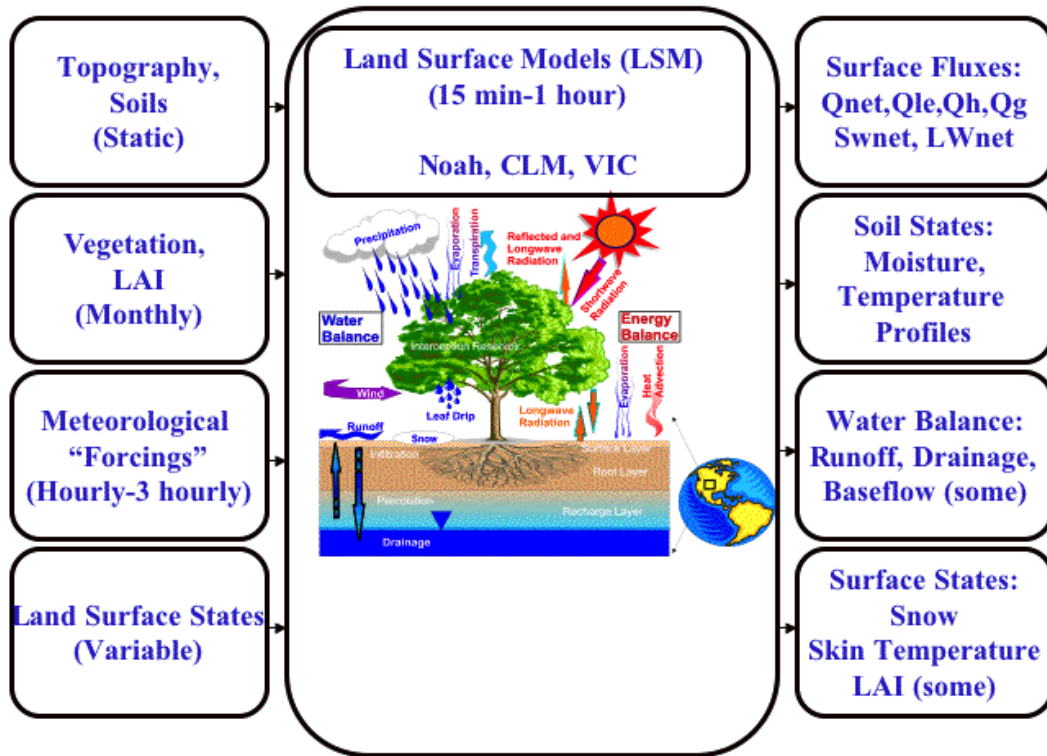


## **Benefit:**

- Demonstrate capability of NASA and NOAA experimental products to weather applications and societal benefit
- Take satellite instruments with climate missions and apply data to solve shorter-term weather problems

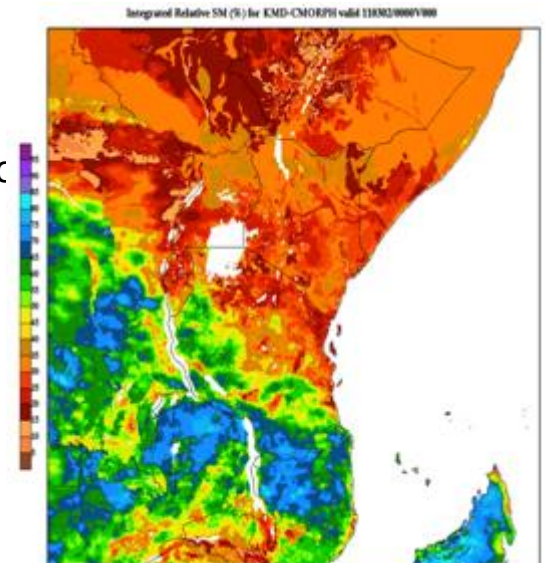


# Land Information System (LIS)



***SPoRT-LIS total column soil moisture displayed in AWIPS II***

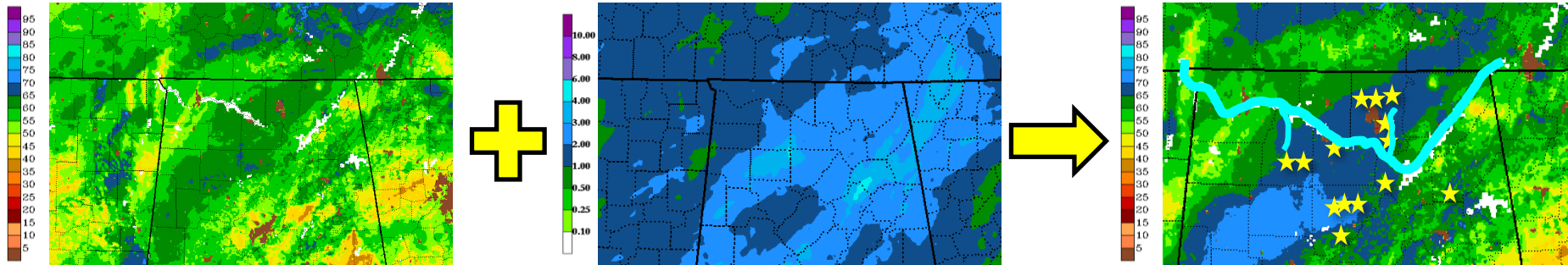
- Framework for running LSMs incorporating a wide variety of meteorological forcing data and land surface parameters
  - Developed at NASA-GSFC
  - Includes data assimilation capability.
  - Can be run coupled with WRF.
- Experiments done in Noah 3.2 Land Surface Model (LSM) within LIS
- NASA SPoRT maintains near-real-time and experimental LIS runs
  - SE US (3-km), shared with WFO's
  - East Africa, shared with Kenya Meteorological Service (KMS)



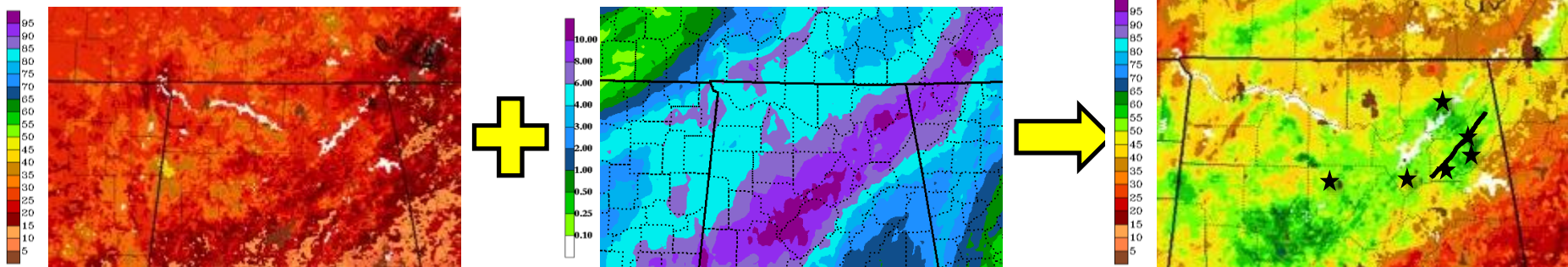
***East Africa LIS domain***

# Applications: Flood Potential

***March – moderate antecedent soil moisture, moderate rain***



***September - low antecedent soil moisture case***



**Contrasting antecedent soil moisture likely played a strong role in the different outcomes**

**Analysis of several events suggests typical moderate-heavy synoptic rainfall events over deep-layer relative soil moisture values exceeding 55-60% will lead to more substantial moderate or heavier flooding events**

# SMOS and SMAP

- L-band radiometers (and radars) can be used to estimate soil moisture near the surface
  - Compared to higher frequency instruments:
    - Sees deeper in the soil (~5 cm)
    - Better vegetation penetration
    - Higher sensitivity (accuracy)
- SMAP radar gives improved horizontal resolution
- Assimilating retrievals from Soil Moisture and Ocean Salinity (SMOS) satellite
- Preparing for assimilation of NASA Soil Moisture Active/Passive (SMAP) retrievals



Name	AMSR-E	SMOS	SMAP		
Agency	NASA/JAXA	ESA	NASA		
Launch	2002	2009	Jan. 2015		
Orbit	Polar	Polar	Polar		
Sensor Type	Passive	Passive	Passive	Active (Failed July 2015)	Combined
Frequency	6.9 GHz (C-band)	1.4 GHz (L-band)	1.41 GHz	1.2 GHz	
Resolution	56 km	35-50 km	36 km	<b>3 km</b>	9 km
Accuracy	6 cm <sup>3</sup> /cm <sup>3</sup>	<b>4 cm<sup>3</sup>/cm<sup>3</sup></b>	<b>4 cm<sup>3</sup>/cm<sup>3</sup></b>	6 cm <sup>3</sup> /cm <sup>3</sup>	<b>4 cm<sup>3</sup>/cm<sup>3</sup></b>

**The SMAP Active/Passive product maintains the high accuracy of SMOS with better spatial resolution, enabling reduced representativeness error due to inhomogeneities.**

# Data Assimilation in LIS

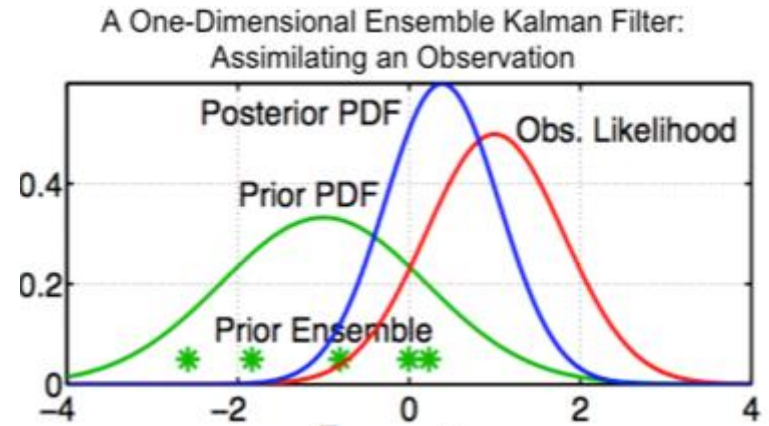
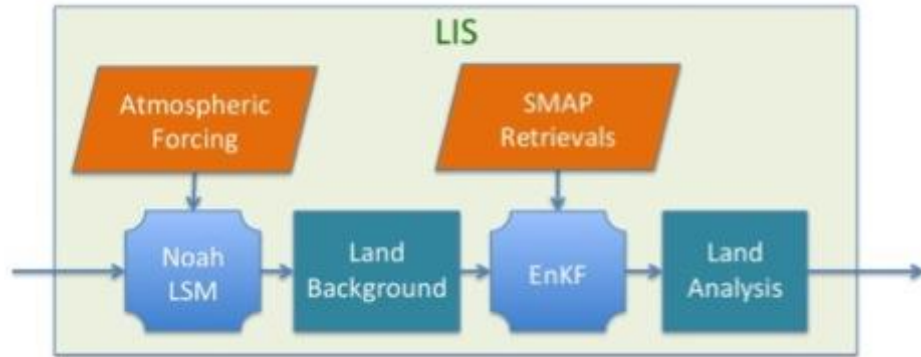
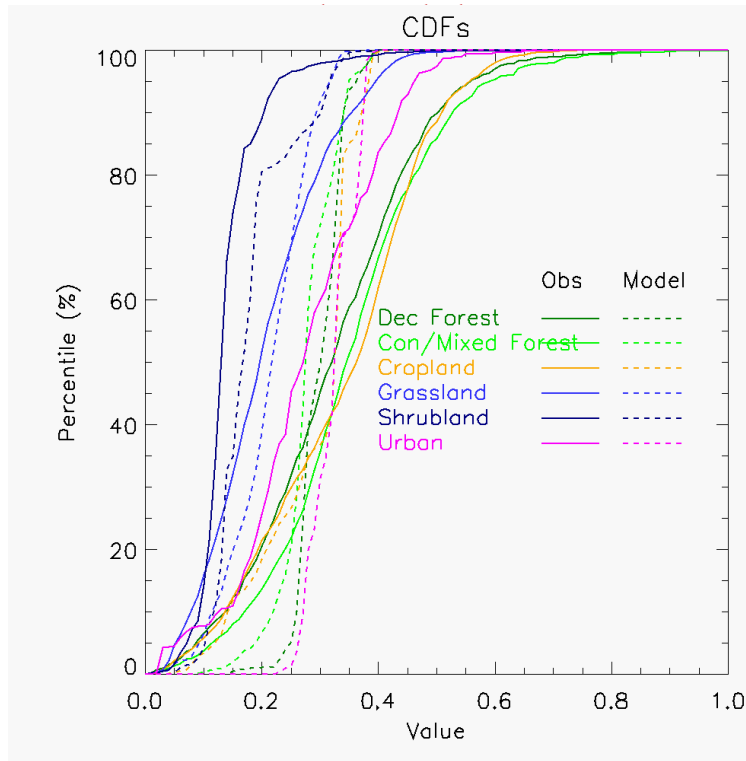


Figure from J. Anderson, NCAR.

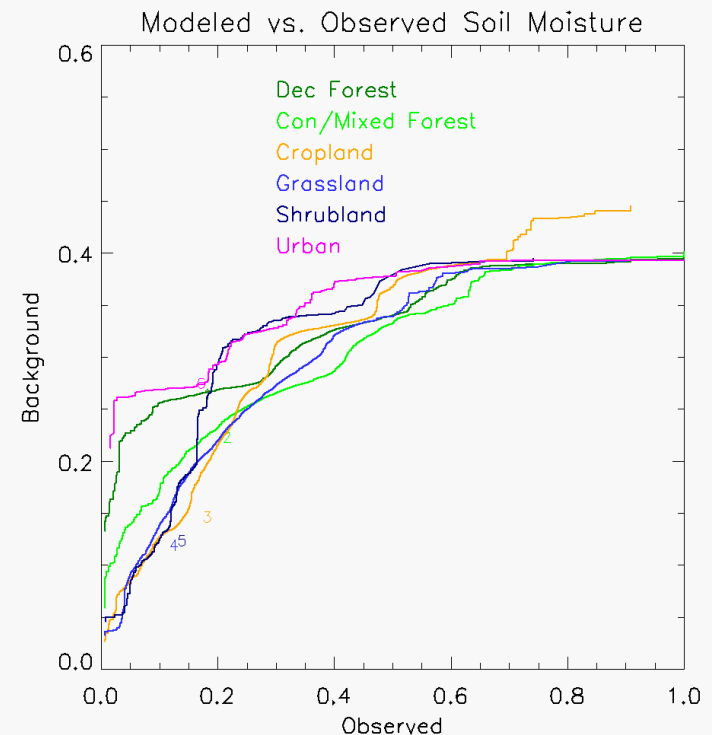
- Uses Ensemble Kalman Filter in LIS
- Combines Background (Model) and Observations (Satellite Retrievals), weighted by their uncertainties, to provide a new analysis
- Observation operator relates the top model layer of soil moisture (0-10 cm) to the bias-corrected observations (~5 cm).
- Better depiction of top layer can improve deeper layers through drainage and diffusion.

# Bias Correction

## CDFs of Soil Moisture Observations



## Correction Curves

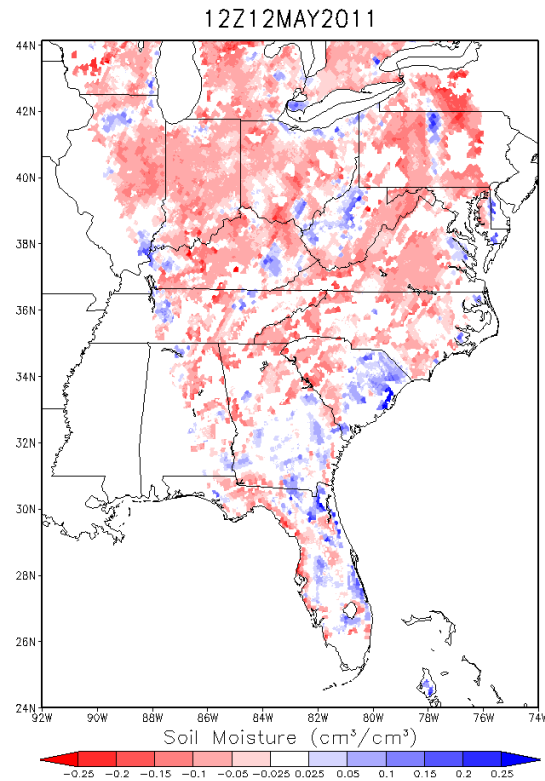


- LIS can apply point-by-point correction curves. To increase the background dataset size, we are aggregating points by landcover type. We will also explore correction at each point and aggregating by soil type.
- In general, observations are drier than the model but have a higher dynamic range.

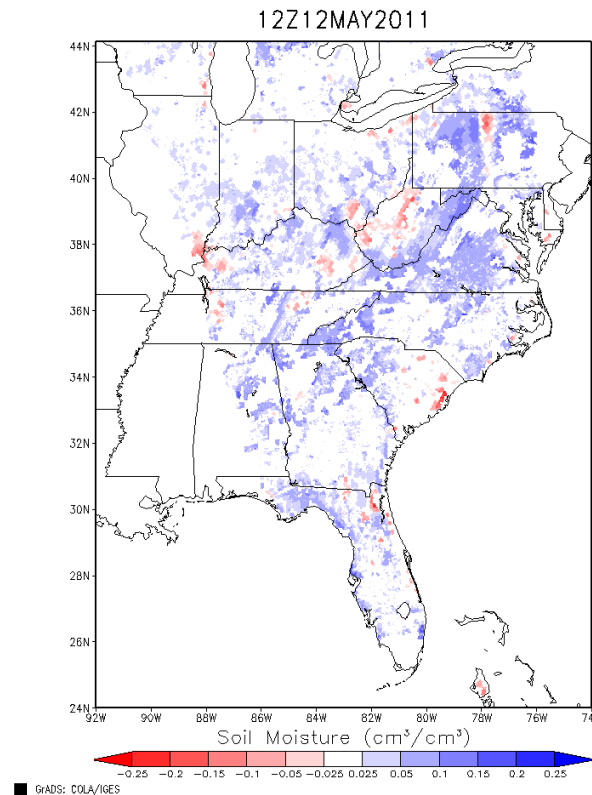
# Bias Correction

- Implemented landcover-based CDF matching correction for SMOS retrievals.

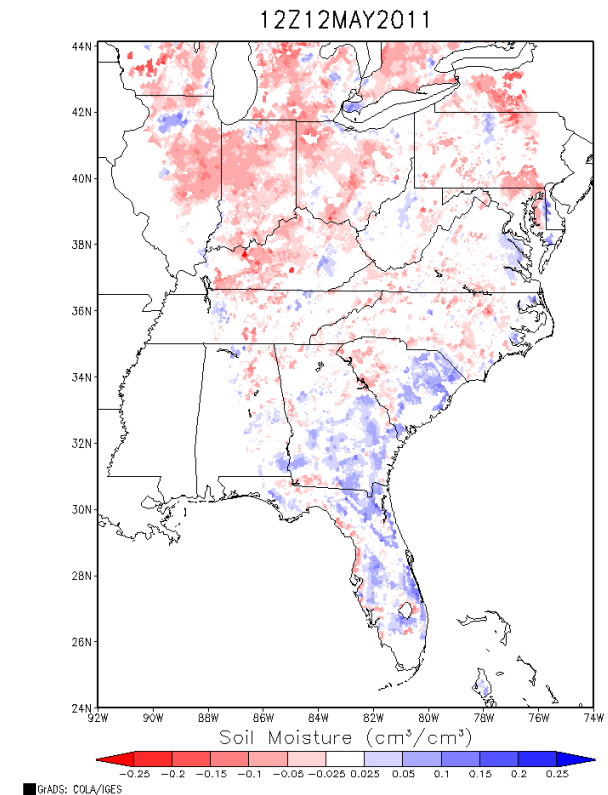
**Innovations (Ob-Bk)  
(Uncorrected)**



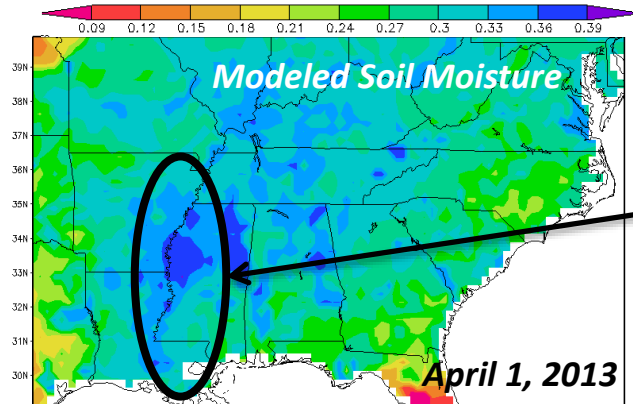
**Bias Correction**



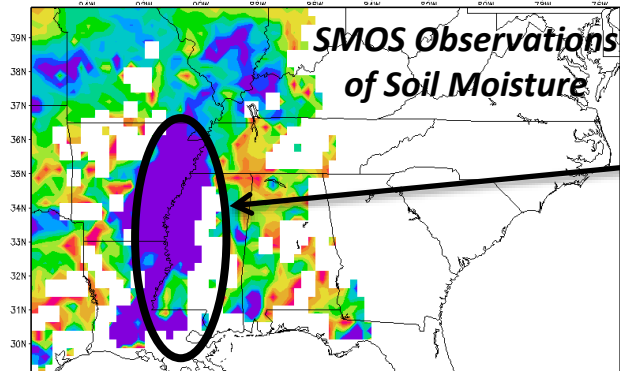
**Innovations  
(Corrected)**



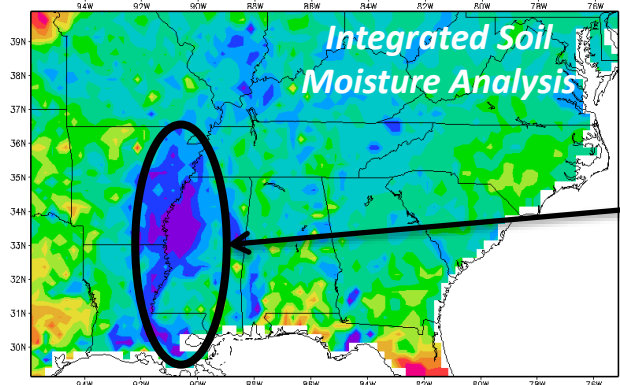
# Example DA (rice irrigation)



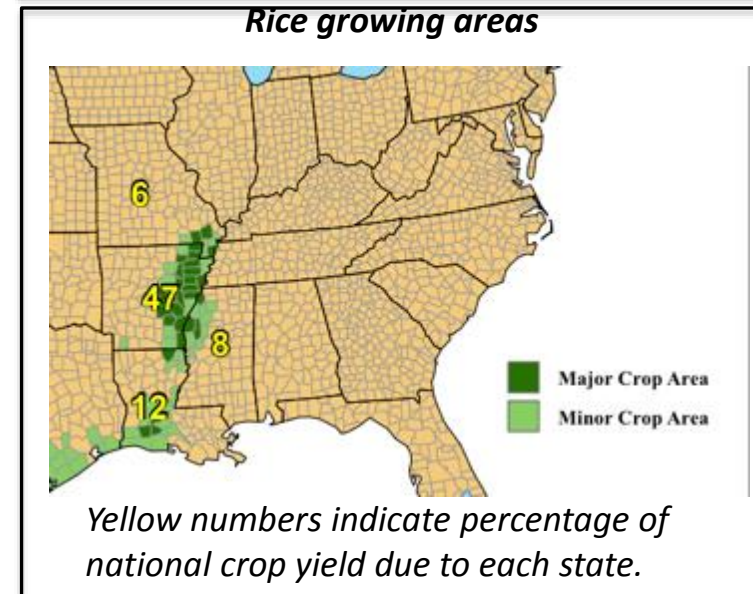
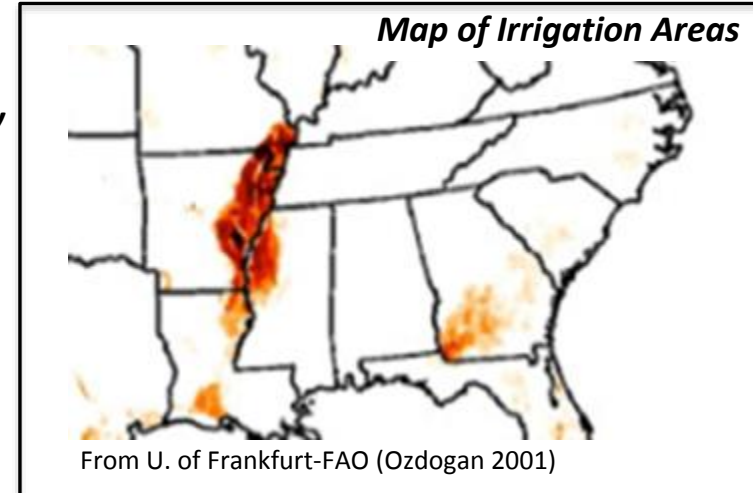
*Model soil moisture concentration forced only by precipitation and misses magnitude of irrigation-saturated MS Valley*



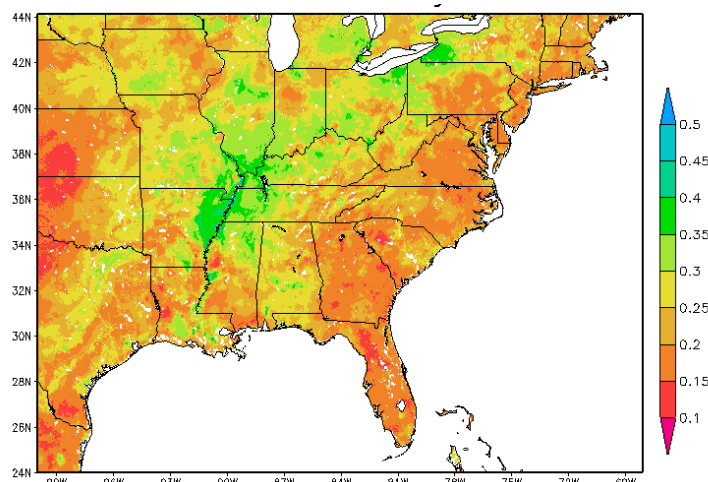
*SMOS observes irrigated fields*



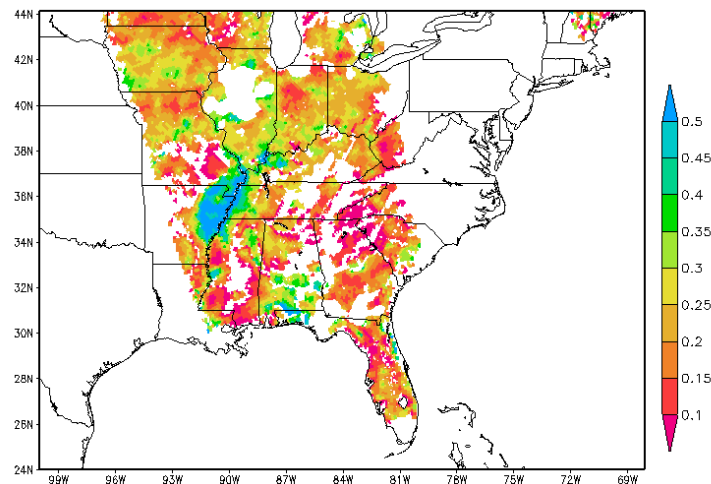
*Blended analysis of model and observations better represent irrigated area and should result in improved weather and hydrologic modeling*



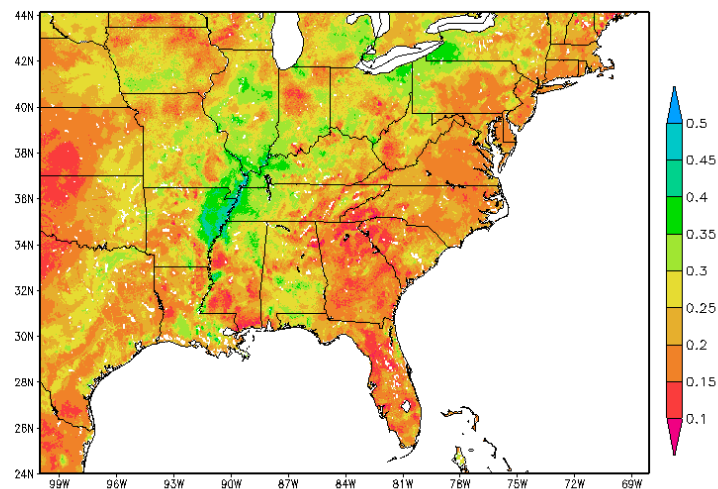
# 3-km results (14 May 2011)



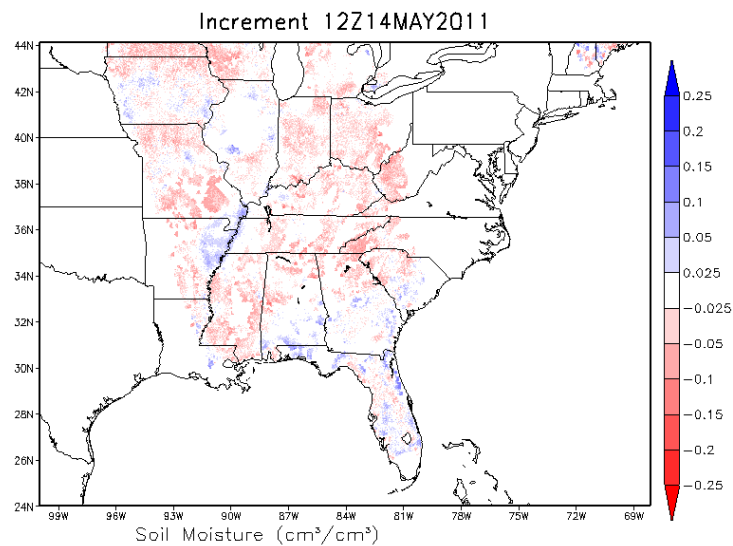
**BACKGROUND**



**OBSERVATIONS**



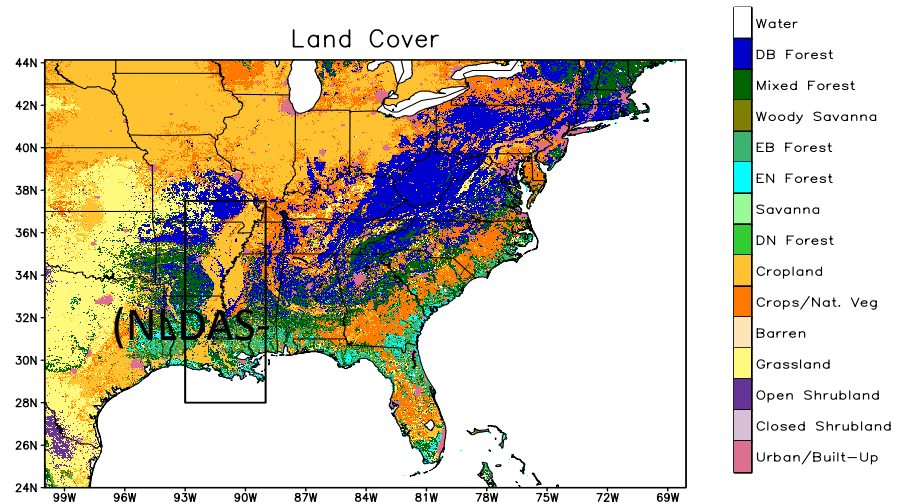
**ANALYSIS**



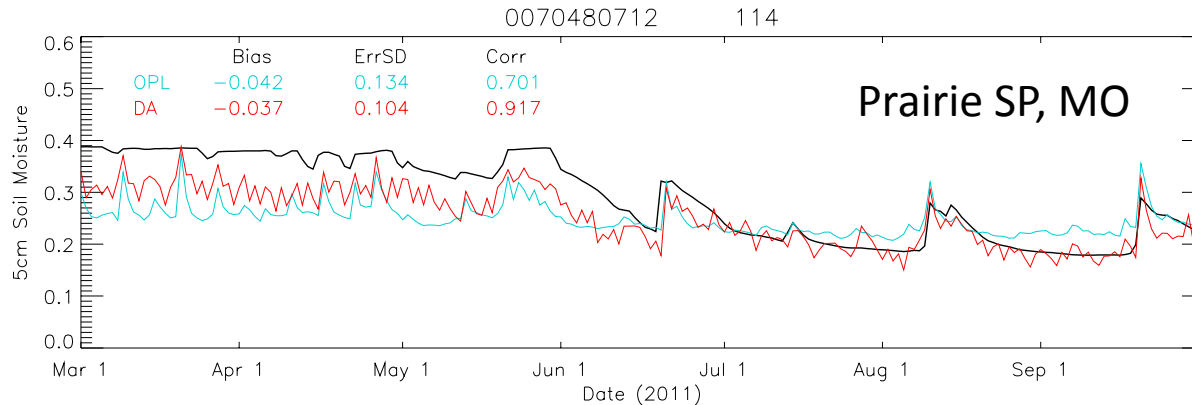
**INCREMENT**

# Experiment Design

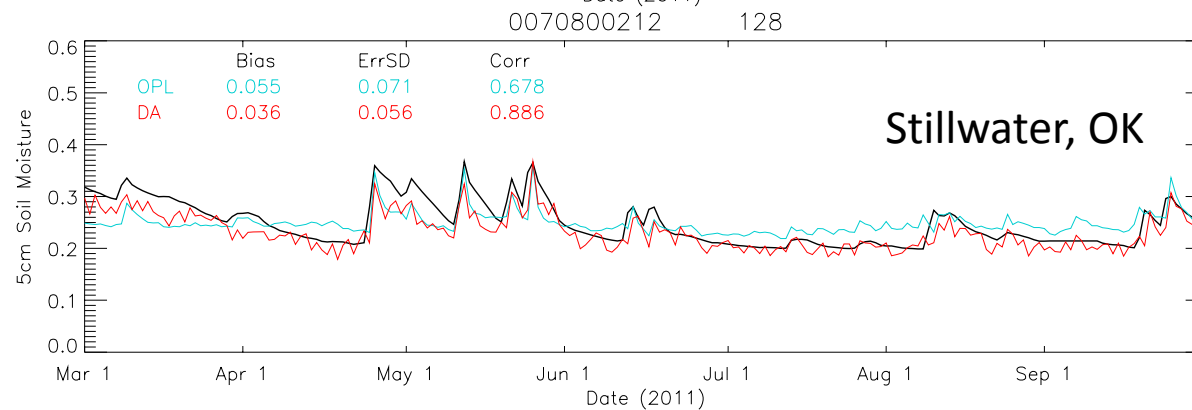
- Southeastern/Central USA 3-km domain
- MODIS/IGBP Vegetation Type
- STATSGO Soil Type
- Daily MODIS GVF
- North American Land Data Assimilation 2 2) forcing
- Precip: Stage IV (radar+gauge)
- 1-yr spinup, 1 month perturbations, 32 ensemble members
- Experiment run March-October 2011
- SMOS DA
  - State, Observation, and Forcing Perturbations
- Control (Open loop with perturbations)
- Validation
  - North American Soil Moisture Database
  - Due to scale mismatch, expect correlations to be most useful metric



# SMOS DA Validation

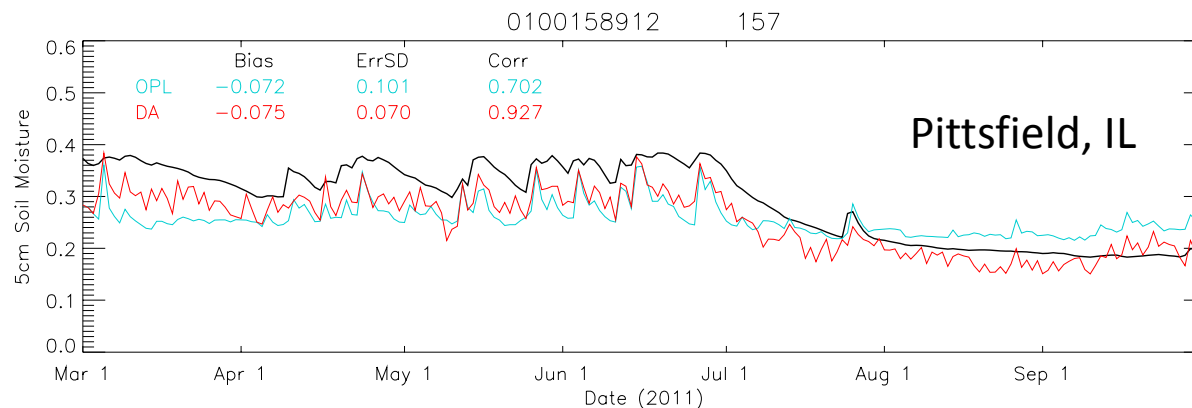


0-10 cm model soil moisture  
Compared open loop run to  
SMOS DA run.



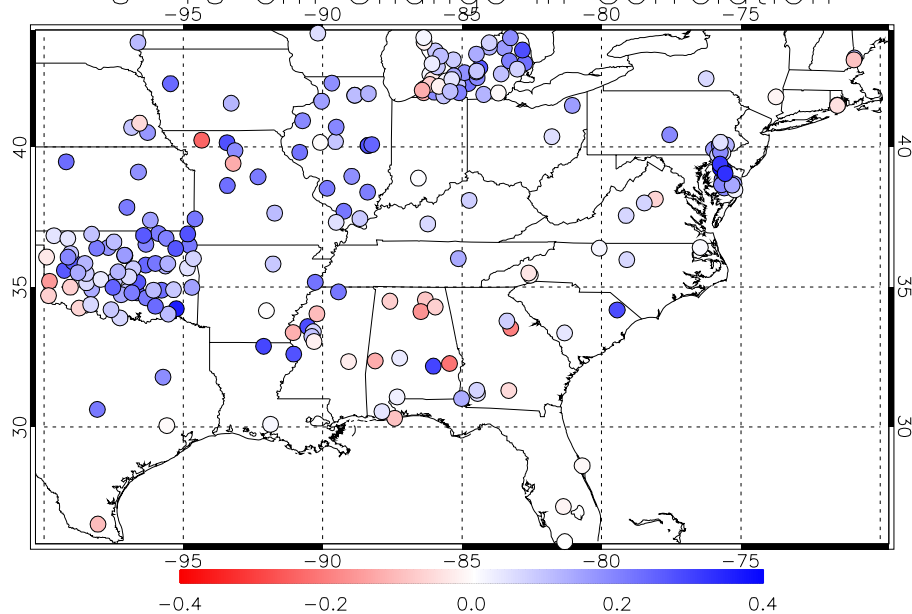
Results from validation  
against soil moisture  
networks in US  
(North American Soil  
Moisture Database)

- Better correlations
- Improved dynamic range

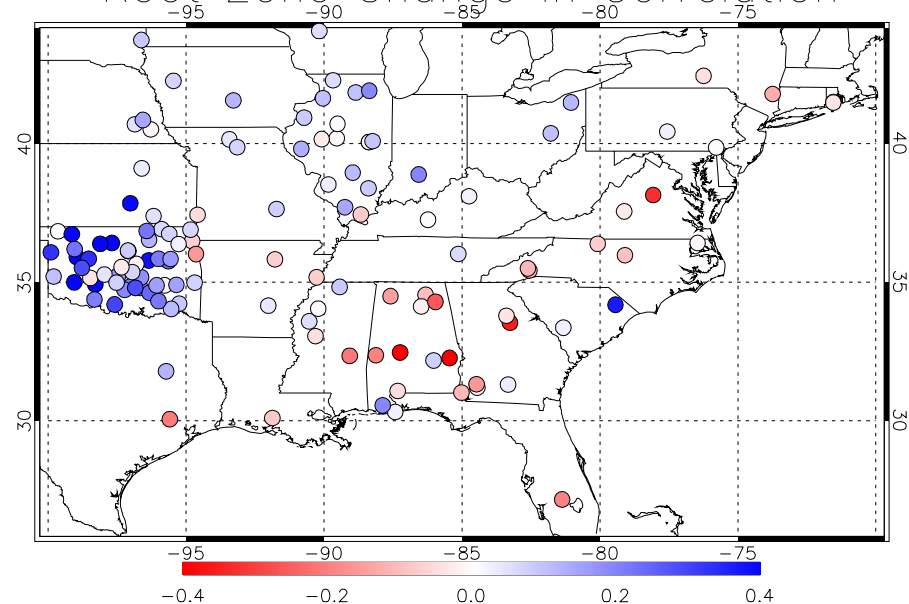


# SMOS DA Validation

0–10 cm Change in Correlation

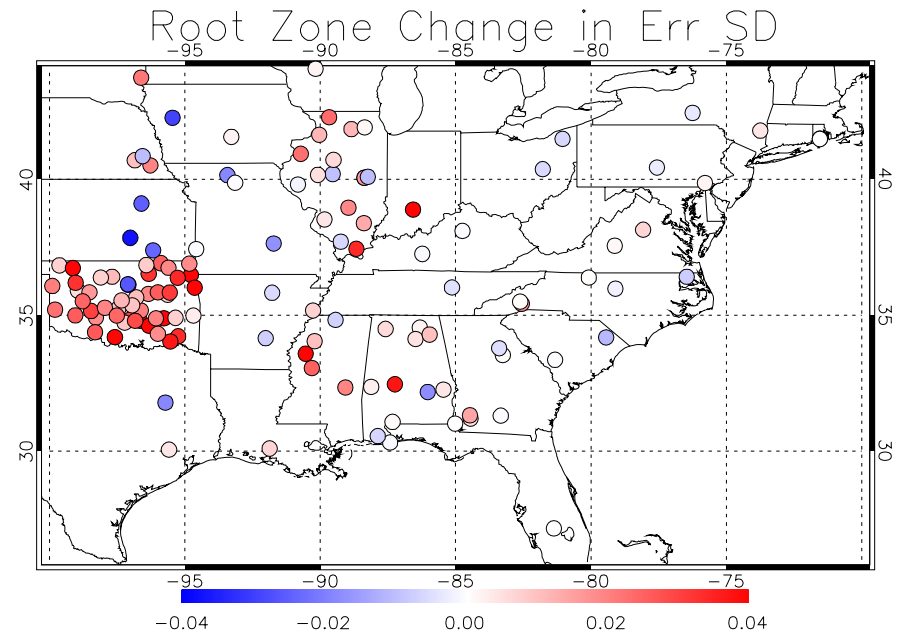
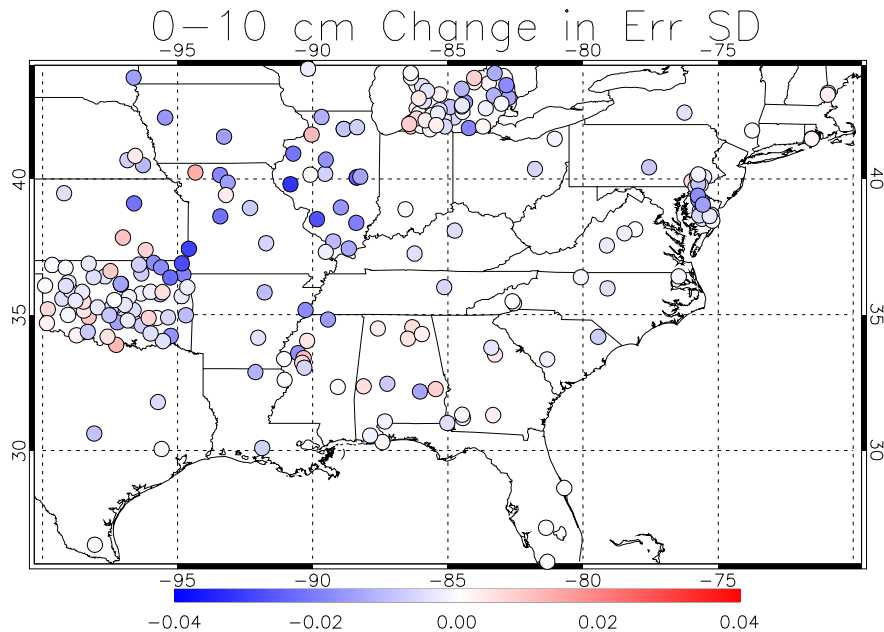


Root Zone Change in Correlation



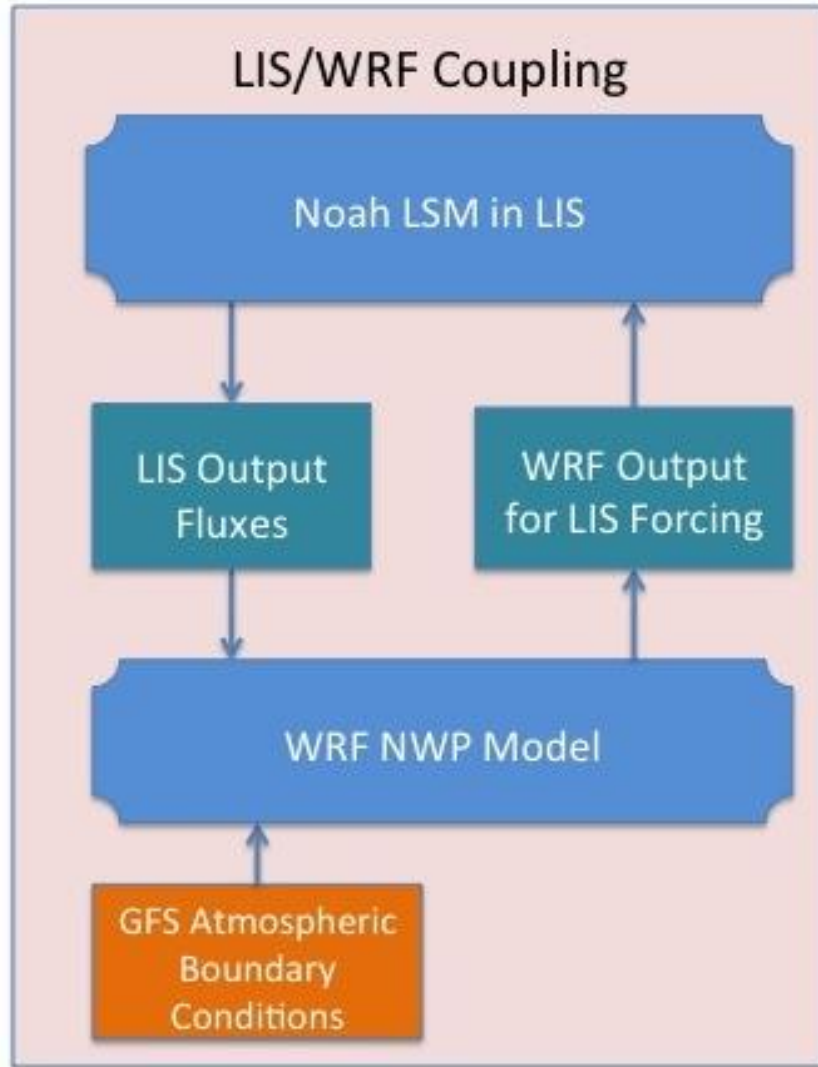
	Near Surface (0-10 cm)			Root Zone (10-100 cm)		
	Bias	Err SD	Corr.	Bias	Err SD	Corr.
<b>Control</b>	3.6%	23.5%	<b>0.47</b>	4.0%	10.6%	<b>0.61</b>
<b>SMOS DA</b>	-0.5%	21.8%	<b>0.57</b>	10.6%	11.8%	<b>0.67</b>

# SMOS DA Validation



	Near Surface (0-10 cm)			Root Zone (10-100 cm)		
	Bias	Err SD	Corr.	Bias	Err SD	Corr.
<b>Control</b>	3.6%	23.5%	<b>0.47</b>	4.0%	10.6%	<b>0.61</b>
<b>SMOS DA</b>	-0.5%	21.8%	<b>0.57</b>	10.6%	11.8%	<b>0.67</b>

# WRF impact tests

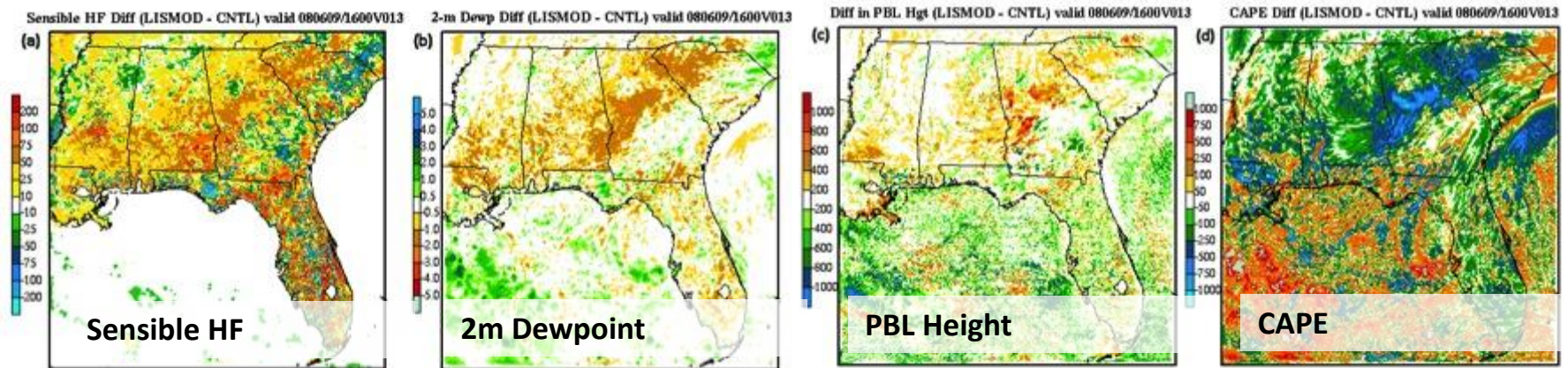


- Coupled LIS/WRF runs
  - NWP provides forcing for LSM
  - LSM provides fluxes and surface conditions to NWP model
- Assess impact of SMAP DA on NWP for coupled runs
  - Verify NWP forecasts against surface obs, soundings, and precipitation analyses
  - Examine impact on significant events

Validation Datasets		
Domain	T, q, wind	Precipitation
CONUS	MADIS	MRMS
East Africa	WMO network	GPM IMERG

# WRF impact tests

- Weather impacts of improved LSM states
  - Moisture
  - Surface fluxes
  - Diurnal heating rates
  - Convection



*Impact of using high-res LIS output in WRF rather than NAM fields.*

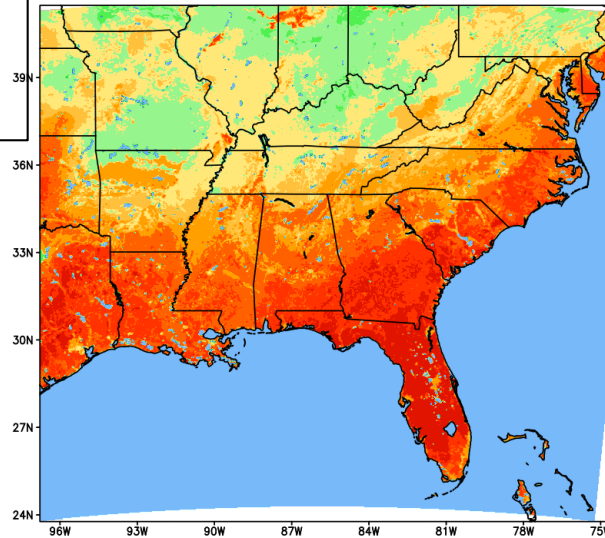
*(Case et al. 2008, J. Hydro.)*

# WRF Impact

## Initial Soil Moisture

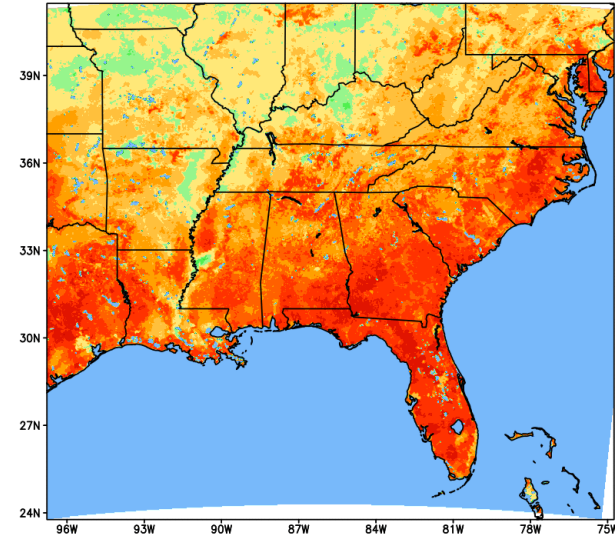
### Open Loop

0–10 cm Volumetric Soil Moisture ( $\text{m}^3/\text{m}^3 \times 100$ )  
OL 0–h Forecast Valid: 00Z 01 JUN 2011

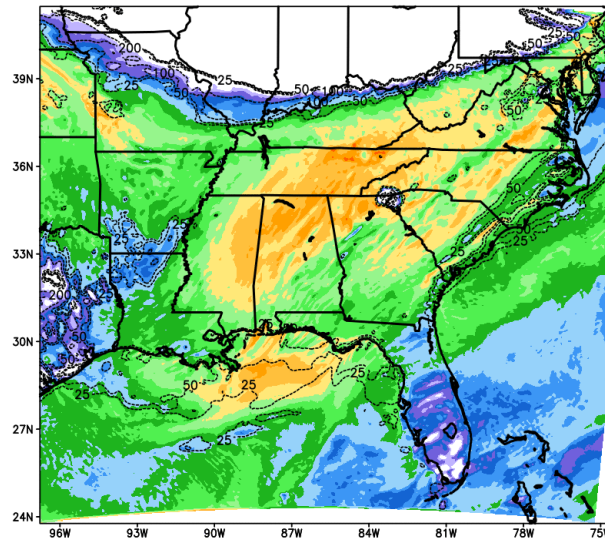


### SMOS DA

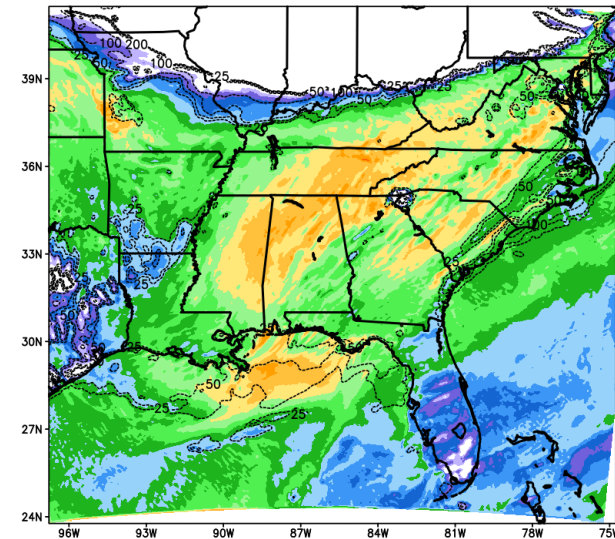
0–10 cm Volumetric Soil Moisture ( $\text{m}^3/\text{m}^3 \times 100$ )  
DABC 0–h Forecast Valid: 00Z 01 JUN 2011



Surface Based CAPE and Magnitude of CIN ( $\text{J/kg}$ )  
OL 21–h Forecast Valid: 21Z 01 JUN 2011



Surface Based CAPE and Magnitude of CIN ( $\text{J/kg}$ )  
DABC 21–h Forecast Valid: 21Z 01 JUN 2011



## CAPE (21-h Fcst)

- Soil moisture and associated surface fields have known impacts on weather
- How much can SMAP retrievals improve weather forecasts?

# Summary and Plans

Successful validation of SMOS DA showing improved correlations with ground observations for upper layer (0-10 cm) and root zone (10-100 cm).

## ***Future Plans***

- Assimilate SMAP data
  - L2 Active-Passive Retrieval (9 km) product (limited time period)
  - L2 Passive Retrieval (36 km)
  - Awaiting info on other SMAP products
- Coupled LIS-WRF experiments using NU-WRF
  - NWP validation over US and East Africa
- Implement DA in near-real-time LIS runs
  - Transition products to NWS and international partners
- Further investigate bias correction

## ***Predicted Impacts***

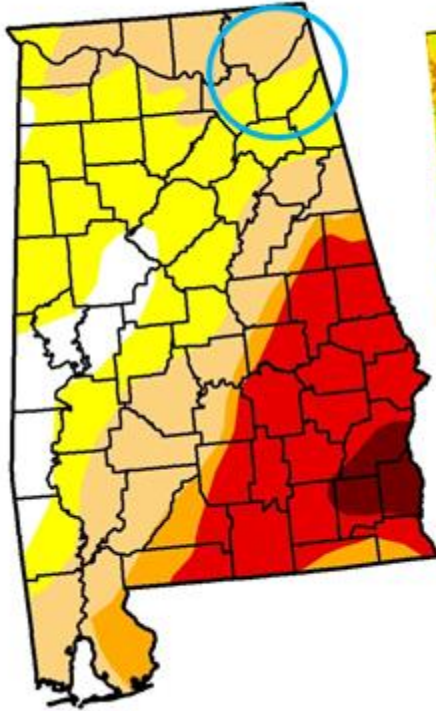
- Improved resolution of SMAP Active-Passive product will reduce representativeness errors due to heterogeneity while maintaining high accuracy
- Better depiction of gradients and structure for coupling with NWP models at convection-allowing resolution (3 km) for regional forecasting



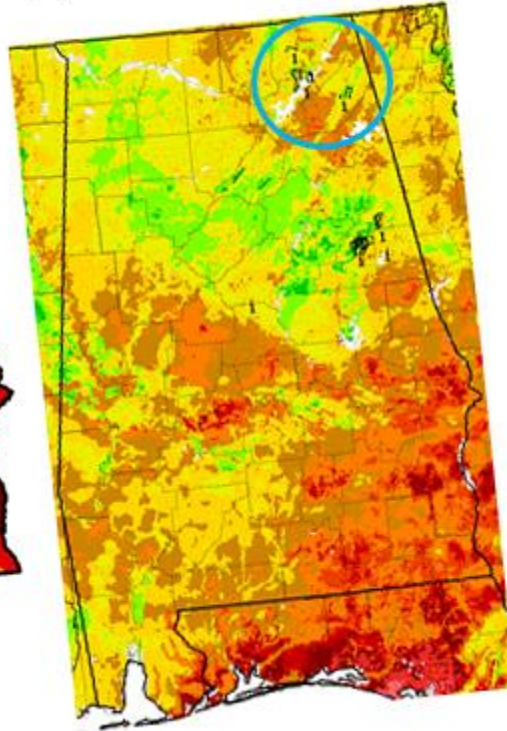
Extras/scratch space...

# Applications: Drought Monitoring

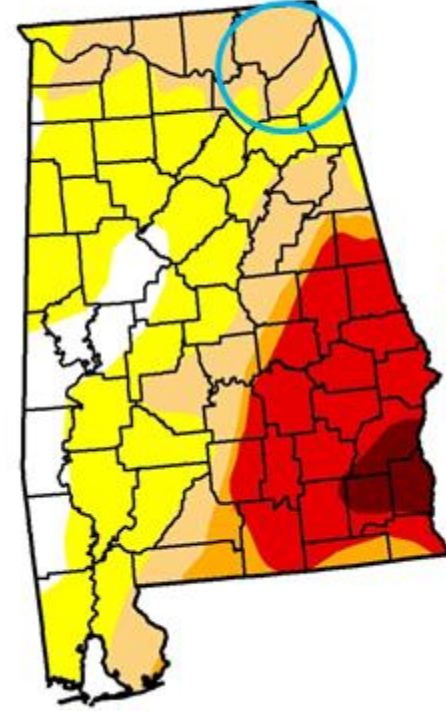
(a) USDM: 1 May 2012



(b) SPoRT-LIS: 8 May 2012



(c) USDM: 8 May 2012



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

- Soil moisture from SPoRT LIS has been used by NWS forecasters to refine drought indices on the county scale (Huntsville, Houston, Raleigh)
- Soil moisture and GVF output from LIS could also be applied to situational awareness and forecasts of red flag warnings and potential for fires